4

GL-TR-90-0024

A REGIONAL FORECASTING MODEL

William H. Jasperson
David E. Venne

Control Data Corporation
Meteorology Research Department
HQB02T
P.O. Box 0
Minneapolis, MN 55440

15 January 1990

Scientific Report No. 1

GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AIR FORCE BASE, MASSACHUSETTS 01731-5000

This technical report has been reviewed and is approved for publication.

Rosemary M. Dyer

ROSEMARY M. DYER
Contract Manager

Donald A. Chisholm

DONALD A. CHISHOLM, Chief
Atmospheric Prediction Branch

FOR THE COMMANDER

Donald A. Chisholm for RAM

ROBERT A. McCLATCHEY, Director
Atmospheric Sciences Division

This report has been reviewed by the ESD Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS).

Qualified requestors may obtain additional copies from the Defense Technical Information Center. All others should apply to the National Technical Information Service.

If your address has changed, or if you wish to be removed from the mailing list, or if the addressee is no longer employed by your organization, please notify GL/IMA, Hanscom AFB, MA 01731. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document require that it be returned.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No 0704-0188

1a REPORT SECURITY CLASSIFICATION: Unclassified

1b RESTRICTIVE MARKINGS:

2a SECURITY CLASSIFICATION AUTHORITY:

2b DECLASSIFICATION / DOWNGRADING SCHEDULE:

3 DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution unlimited

4 PERFORMING ORGANIZATION REPORT NUMBER(S):

5 MONITORING ORGANIZATION REPORT NUMBER(S): GL-TR-90-0024

6a NAME OF PERFORMING ORGANIZATION: Control Data Corporation

6b OFFICE SYMBOL (If applicable):

7a NAME OF MONITORING ORGANIZATION: Geophysics Laboratory

6c ADDRESS (City, State, and ZIP Code): Meteorology Research Department, HQB02T, PO Box 0, Minneapolis, MN 55440

7b ADDRESS (City, State, and ZIP Code): Hanscom AFB, Massachusetts 01731-5000

8a NAME OF FUNDING / SPONSORING ORGANIZATION:

8b OFFICE SYMBOL (If applicable):

9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: F19628-89-C-0015

8c ADDRESS (City, State, and ZIP Code):

10 SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO	PROJECT NO	TASK NO	WORK UNIT ACCESSION NO
62101F	6670	10	DD

11 TITLE (Include Security Classification): A Regional Forecasting Model

12 PERSONAL AUTHOR(S): William H. Jasperson; David E. Venne

13a TYPE OF REPORT: Scientific #1

13b TIME COVERED: FROM ______ TO ______

14 DATE OF REPORT (Year, Month, Day): 1990 January 15

15 PAGE COUNT: 14

16 SUPPLEMENTARY NOTATION:

17 COSATI CODES

FIELD	GROUP	SUB-GROUP

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Expert System; Artificial Intelligence; Weather Forecasting

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

The objective of this three year project is to develop an expert system which can be used to make a short-range weather forecast from limited data. The expert system will not be tied to any particular station. This will be done by determining and utilizing the physical relationships between the synoptic weather and variables that affect the local weather such as terrain, geography and surface type.

The first year's work included software selection, knowledge design issues, tentative class and object networks and structuring of the expert system. The bases for these discussions and the description of progress on various pieces of the system are described in this report.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21 ABSTRACT SECURITY CLASSIFICATION: Unclassified

22a NAME OF RESPONSIBLE INDIVIDUAL: Rosemary Dyer

22b TELEPHONE (Include Area Code):

22c OFFICE SYMBOL: GL/LYP

DD Form 1473, JUN 86 — Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

CONTENTS

ILLUSTRATIONS

I. Introduction

The objective of this project is to develop an expert system which can be used to make a short-range weather forecast from limited input data. The expert system will not be tied to any particular station. This will be done by determining and utilizing the physical relationships between the synoptic weather and variables that affect the local weather such as terrain, geography and surface type.

This interim report describes our opinions and progress at the end of the first year of this three year contract. During this period, hardware and software options have been reviewed and selected. Knowledge design issues have been examined and some tentative class and object networks have been defined for the observation database, the geographic database and the synoptic description. A major decision has been made about the structuring of the expert system into subdomain knowledge bases that can be called upon at the appropriate time in the system's operation. The basis for this decision and the description of progress on various software pieces of the system are described in this report. Work in the second year will begin to tie many of these pieces together as we move to construct a functional expert system.

II. Evaluation of Hardware and Software

A. Hardware

The hardware choices available to the developer and user of a complex expert system are limited to mainframe computers, AI workstations, general-purpose workstations, and high-end microcomputers. Expert system development software exists for all classes of machines with cost and capabilities increasing with machine power. Mainframes and workstations are relatively expensive, and expert systems developed on these machines may not be readily ported to more common and affordable machines. Conversely, the wide distribution of relatively inexpensive IBM-compatible microcomputers based on 80386 (and, in growing numbers, 80486) processor technology makes them an attractive choice for projects of scope similar to that undertaken here.

During the first quarter of the project it was decided to use an 80386-based microcomputer (specifically, a Zenith 386) as the initial hardware environment. Although the microcomputer is the least powerful of the hardware options mentioned above, it was judged to have adequate capabilities for the current project. The choice of an 80386 was made with the knowledge that suitable expert system software development environments were available commercially. The 80386 was also chosen because it permits effective use of graphics with adequate resolution (640 by 480 pixels, 16 colors) for the display of meteorological data, charts and other products. In light of this decision, a 4 Mb add-on memory card was purchased for the development machine to provide sufficient expansion memory.

B. Software

A survey of available expert system development tools was made to determine which would be most suitable for the needs of the project. Considerations of cost, capabilities, and ease of use were primary, and the tool had to be

available for 80386 machines. The final candidates were ES, an in-house expert system shell, and NEXPERT, a product of Neuron Data Incorporated. While ES was attractive because the previous Weather Forecasting Expert System (WFES) had been built using it and its cost was negligible, the system's long-term support was uncertain. NEXPERT was judged the better candidate because of its wide range of features, convenient user interface, and portability of knowledge bases (KBs) between mainframes, workstations and microcomputers. Support for NEXPERT seemed more stable given its growing acceptance in the AI marketplace.

Another NEXPERT feature that was found to be especially desirable is its ability to be used in an embedded form, allowing the developer to invoke KBs from high-level languages. This facilitates the separation of domain knowledge from program control structure, the latter being difficult, or at least cumbersome, to express in KB form. Past experience has shown that the considerable control structure in expert systems can, when coded into KBs, degrade the clarity of KB meaning. Using the NEXPERT KBs and library functions in embedded form allows the developer to use library functions developed by other vendors as well. This is particularly relevant, as the current project requires the use of graphics libraries and a large number of meteorological computation functions.

The NEXPERT expert system development environment and NEXPERT run-time library for IBM PCs were purchased during the third quarter.

III. Knowledge Design

A. Knowledge Bases

Experience suggests that small and single-purpose KBs (typically having less than 100 rules) are easier to develop, revise, and test. Smaller KBs have fewer rules that must be made functional, generally require fewer inputs, and are conceptually simpler to understand and deal with. Such KBs are also more efficient for being embedded within a larger program where they can be loaded when needed and unloaded when their processing is completed. This modularity can help produce faster, more efficient programs and can reduce development time.

The ongoing design of the WFES makes use of smaller KBs. Although still undergoing development, the knowledge structure of the WFES will be placed in a hierarchy. The highest, or global KB will carry all the classes, objects and constants that are present throughout the forecasting session. Secondary KBs will be loaded when specific tasks are undertaken (such as loading surface data, performing an analysis, etc.) and will include quantities with scope limited to the task. Small KBs that perform more specialized functions, such as determining the airmass, will be loaded as needed.

The analysis process exemplifies the approach of using ordered KBs (Figure 1). The Global KB, loaded at program initiation, maintains the classes and objects needed to describe observations, climate and geography data. The loading of the Analysis KB defines additional classes and objects whose scopes are limited to the analysis process. These classes and objects will be visible to all subsequent KBs until the Analysis KB is unloaded. An Airmass KB is loaded to determine the airmasses present, stores the new information in objects

belonging to the analysis KB, and is unloaded. Similarly, other KBs are loaded, executed, and unloaded until the analysis is complete. At the conclusion of the analysis phase of the program, only the analysis KB remains to hold the analysis itself.

B. Classes and Objects

Class and object networks are useful structures for the defining and sharing of properties and values between both physical and abstract entities. A class can define the properties that are distinct to a concept, and an object can represent a realization of the concept. In this study, the main class networks contain information about weather entity relationships, observation and forecast properties, the spatial nature of weather entities, geographic features and climate types.

An early version of the weather entity and geometry networks (Figure 2) demonstrates the simple hierarchy involved in defining weather features. For example, Figure 3 illustrates that an cold front can be a member of the class COLD_FRONT, which is a subclass of the class FRONT. FRONT, in turn, is a subclass of the classes ENTITY and MOVING_LINE. MOVING_LINE is a subclass of LINE, and LINE is a subclass of GEOMETRIC_ELEMENT. The actual cold front is expressed as an object that has properties inherited from its ancestor classes. The object inherits properties specific to all fronts (such as vertical slope, associated airmasses, intensity) from FRONT, properties unique to cold fronts (e.g., the likelihood of a steeper slope) from COLD_FRONT. Also inherited are the properties and attributes of line-like features from LINE and the properties needed to describe the motion of a line from MOVING_LINE.

IV. Implementation

A. Control Shell

Experience has shown that expert systems often require a considerable control structure to internally regulate their activities. The control structure can be characterized as procedural instructions that are virtually devoid of what is classically referred to as "knowledge". Because they contain little knowledge, they are not as well expressed within a KB as they might be in a more procedural language such as C or Pascal. While the separation of procedural information from knowledge can never be complete, it would seem advantageous to use a high level language such as C to regulate KB activity, thereby keeping the latter "cleaner".

The use of a C "shell" program that contains the procedural information also has advantages for expert system development. KBs designed and built using the NEXPERT development environment can be tested as stand-alone entities. However, their integration with other KBs becomes more difficult as the number and size of the system KBs grow. Since the KBs will ultimately be integrated within a C shell that will supply and manage many of the KB inputs and outputs, it is logical to construct the shell in the early stage of KB development. The shell can then accept each new KB as it comes "on line" and test it in the environment for which it was intended. Because the shell manages the complex climate, geography and observation databases, these databases can be used to test the KBs in an efficient manner. Without the

shell, only simple data can be used in testing because of the memory and speed limitations of the development environment.

For these reasons the implementation of a C shell for the WFES has been started. The shell presently performs the functions of graphical user interface, surface data editor, and platform for KB integration. The user interface is devised to guide the user through the following tasks: selection of database information; loading of data; production, inspection, and modification of analyses; and production, inspection, and modification of forecasts. The interface "locks out" options or tasks that are inappropriate and indicates when analyses or forecasts are no longer current (i.e., new observations have been loaded or analyses have been modified).

B. Geographic Database

Geographic data will be used by the expert system to determine the representativeness of surface winds, the location of nearby bodies of water that may modify local conditions, the presence of large-scale topographic features, etc. In addition, the data will supply a graphic map of the forecast area, incorporating topography, seas, lakes and rivers, political boundaries and landmarks.

A geographic database program has been created that interrogates simple map and geography datasets and creates data files that are tailored for use by the WFES at a designated location. These products include: grids of elevation above sea level, land use, water coverage, and urbanization; map elements that define land areas, lakes, rivers, islands, and political boundaries; and an chart of the forecast area that displays all of the above-mentioned data on an azimuthal equidistant projection. At the present time the resolution of the geographic data is about 15 to 20 miles.

Currently under development is a class/object description of geographic features that can affect meteorological conditions. An example is the class LAKE (see Figure 2), which could have the properties of surface temperature, frozen/liquid status and depth. LAKE would also have the properties of area, shape, orientation, defining points and location relative to the forecast site that it inherited from the superclasses STATIC_REGION and REGION.

The full geographic description should be completed by second quarter of year two.

C. Observation and Forecast Displays

The most acceptable and efficient way to convey meteorological information to the forecaster has been through graphic presentations. In recognition of this fact, a number of graphic interfaces will be created for the WFES so that its actions and conclusions can be understood by the user. Two interfaces that have been created during the first year of the contract and are now functional are designed to depict the 12-hour forecast and observations of the past five days.

The forecast display (Figure 4) is a mixed text-graphics presentation. Text fields provide forecast values of temperature, pressure, and so on, while winds are shown using wind barbs and cloud types are depicted by their

standard symbols. Temperature and pressure changes are emphasized by up or down arrows, and visibility is given both in text and visual form.

The long period display of past observations and forecast is more purely graphic, taking the form of colored charts of temperature, pressure, wind and clouds. This presentation provides rapid understanding of past meteorological events and conditions by plainly showing important surface features such as wind gusts, wind shifts, and changes in cloud amount and height.

V. Plans for Year 2

A. System Design

The use of a shell for the KBs places the burden of planning on the organization and ordering of KBs. The shell itself will need to interact with the KBs, maintain the databases, and perform other graphic services. These are largely procedural tasks, however, and can be dealt with using relatively routine solutions. The more difficult division of knowledge into small KBs, the ordering of KBs and the design of KB hierarchy all will demand greater care. Finalizing the system design will be the first priority of Year 2.

Concurrent with (and a part of) system design will be the finalization of the class and object networks needed to describe the physical entities within the system. Network design is inherently a part of system design when the system is made up of many overlapping and nested KBs, each needing a specific range of classes and objects in order to function.

B. Knowledge Bases

When the system design is finalized the encoding of forecaster knowledge can begin. This will start with the building of KBs to interrogate single observations for airmass types, then progress through other KBs to defining the current synoptic state (or model). The following development will add the ability to deal with time series of data, thereby completing what is called the Analysis KB in Figure 2. At this point the first round of evaluation and validation will be performed and the KBs modified according to the results.

C. Integration

A number of capabilities will be integrated with the shell that are now functional as stand-alone programs. These include graphics routines for observation and simple forecast display, geographic database viewers and the upper air sounding analysis package developed prior to this contract. New graphics routines to be coded and integrated include the upper air observation editor and a sophisticated viewer of the analysis and forecast models.

Newly-created KBs will be integrated with the shell as they become functional, so that during the evaluation and validation phase of Year 2 the entire system (as exists at that time) will be exercised rather than a collection of pieces.

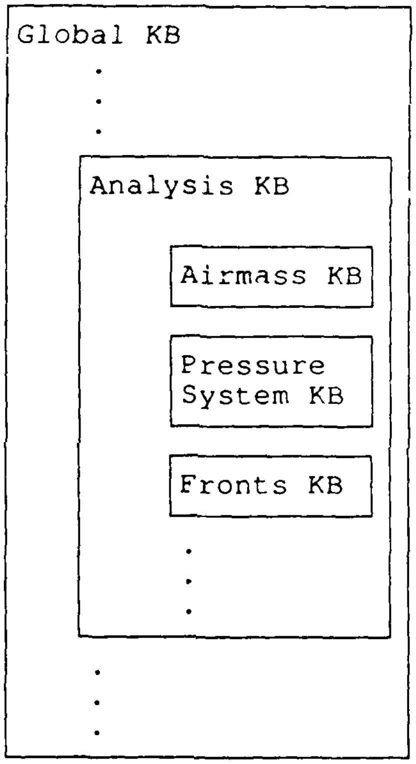

FIGURE 1. Example of Knowledge Base Structure

```
ENTITY
├──AIRMASS
│  ├──ARCTIC_AIRMASS
│  │  ├──cA
│  │  └──mA
│  ├──POLAR_AIRMASS
│  │  ├──cP
│  │  └──mP
│  └──TROPICAL_AIRMASS
│     ├──cT
│     └──mT
├──CYCLONE
├──FRONT
│  ├──COLD_FRONT
│  ├──WARM_FRONT
│  ├──STATIONARY_FRONT
│  └──OCCLUDED_FRONT
├──TROUGH
├──RIDGE
├──PRESSURE_SYSTEM
│  ├──HIGH
│  └──LOW
└──TROPICAL_SYSTEM
   ├──HURRICANE
   ├──TROPICAL_STORM
   └──TROPICAL_DEPRESSION

GEOMETRIC_ELEMENT
├──POINT
│  ├──MOVING_POINT
│  │  ├──PRESSURE_SYSTEM
│  │  └──TROPICAL_SYSTEM
│  └──STATIC_POINT
│     └──LANDMARK
├──LINE
│  ├──MOVING_LINE
│  │  ├──FRONT
│  │  ├──TROUGH
│  │  └──RIDGE
│  └──STATIC_LINE
│     ├──RIVER
│     ├──ROAD
│     └──MOUNTAIN_RIDGE
└──REGION
   ├──MOVING_REGION
   │  └──AIRMASS
   └──STATIC_REGION
      ├──LAKE
      ├──OCEAN
      ├──ISLAND
      ├──MOUNTAIN_RANGE
      ├──VALLEY
      ├──BASIN
      └──CITY
```

FIGURE 2. Class Relationships in the WFES

```
GEOMETRIC_ELEMENT
└────LINE
     └────MOVING_LINE
          │
          │         ENTITY
          │         │
          └─────────┴────FRONT
                         └────COLD_FRONT
```

FIGURE 3. Relationship of COLD_FRONT Class to ENTITY And GEOMETRIC_ELEMENT

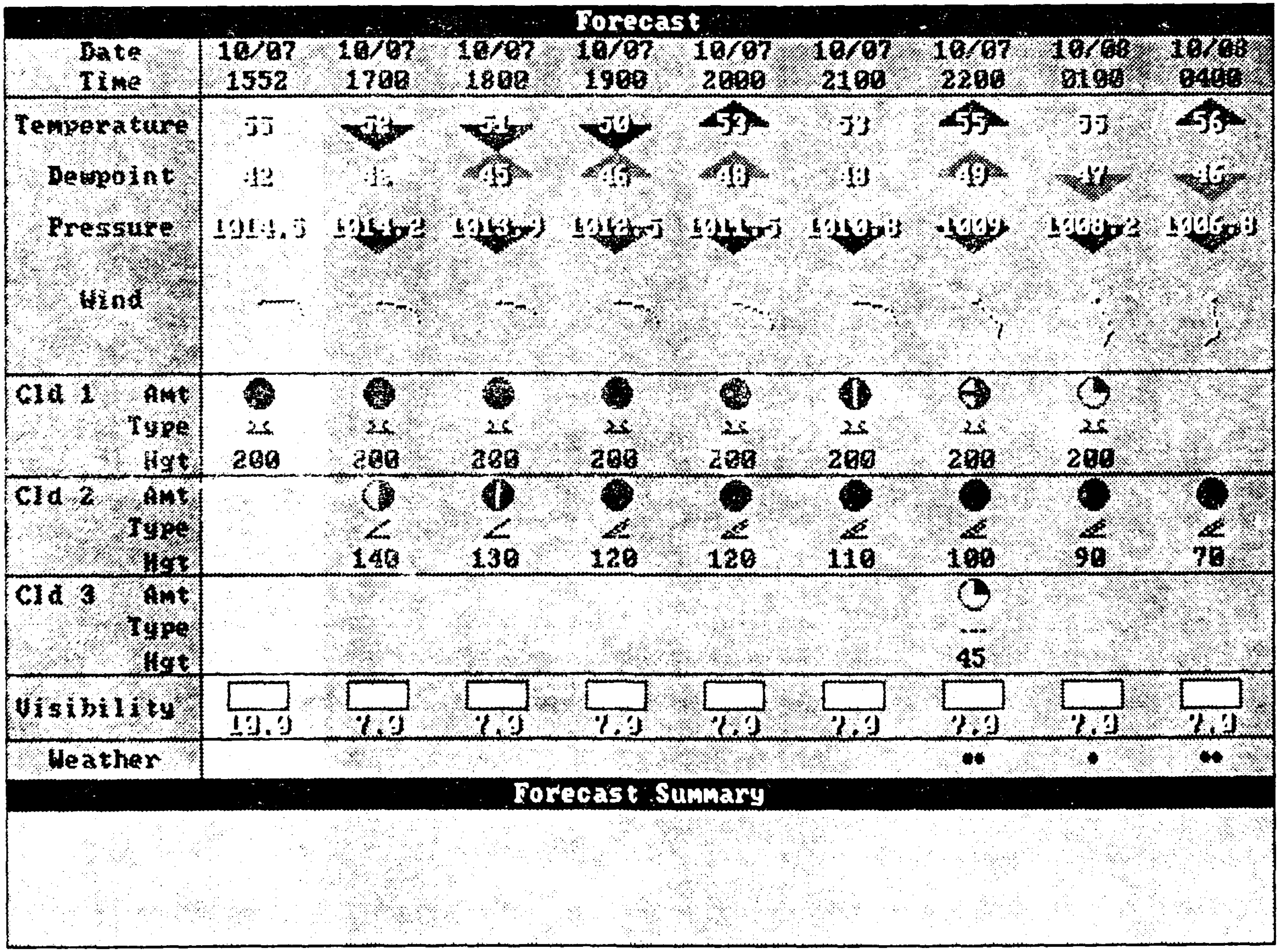

FIGURE 4. Example of the Forecast Display